The Photocathode Program at ANL (LAPPD-Program)

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PC-Group

Outline

- Introduction to Photocathodes
- The Organization and Infrastructure
- Science Highlights
- Conclusion and Outlook

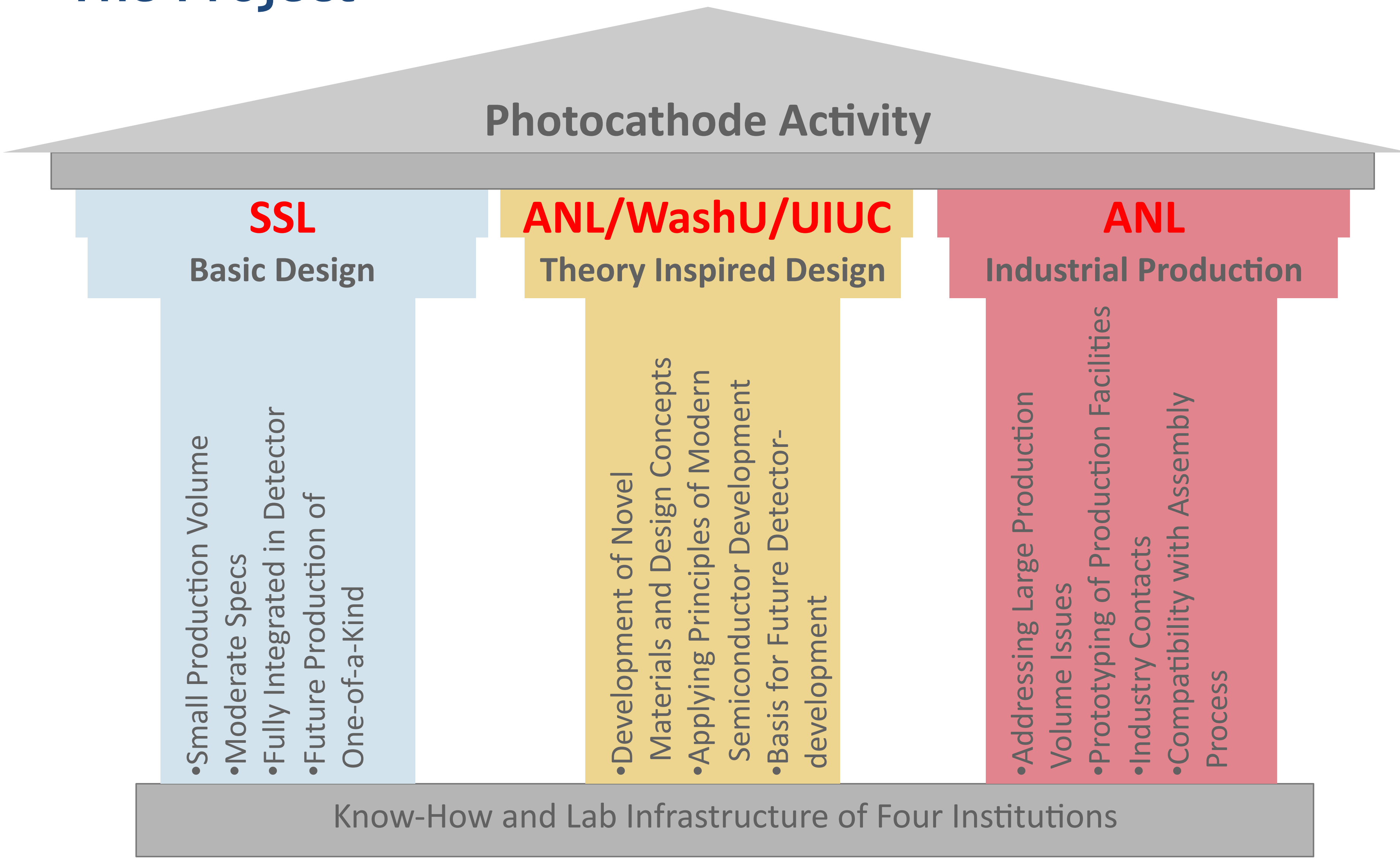
The Goals of LAPPD (DOE-Milestones)

- Demonstration of gain of 106 and aging performance comparable to or better than that of commercial plates with a pair of capillary MCP plates functionalized by ALD;
- Development of an MCP test facility capable of handling 8" plates in tiles;
- Functionalization of an 8" × 8" glass capillary substrate with ALD;
- Observation of gain from an ALD-functionalized 8" × 8" MCP plate;

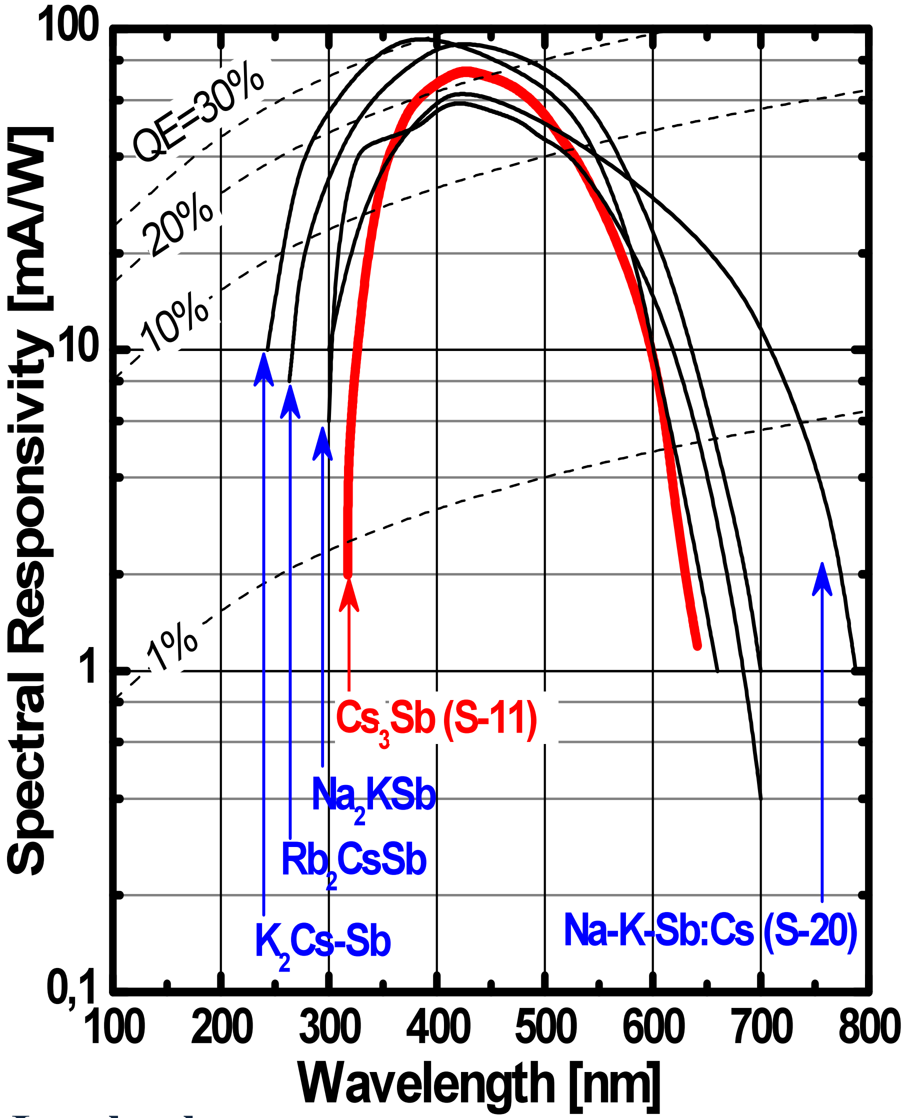
- Design and costing of a photocathode characterization facility;

- Design and costing of an 8" glass tile assembly facility.

The Project


Photocathode Activity
SSL
Basic Design
•Small Production Volume
•Moderate Specs
•Fully Integrated in Detector
•Future Production of One-of-a-Kind
ANL/WashU/UIUC
Theory Inspired Design
•Development of Novel Materials and Design Concepts
•Applying Principles of Modern Semiconductor Development
•Basis for Future Detector-development
ANL
Industrial Production
•Addressing Large Production Volume Issues
•Prototyping of Production Facilities
•Industry Contacts
•Compatibility with Assembly Process
Know-How and Lab Infrastructure of Four Institutions

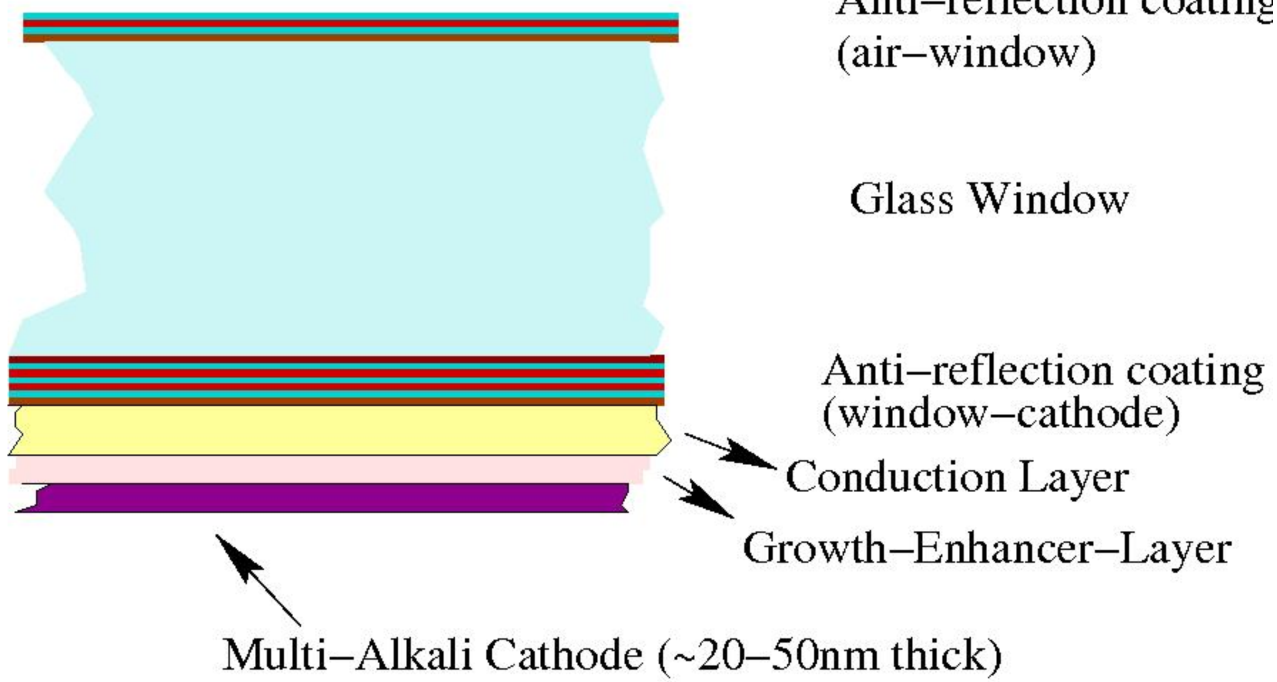
Selection of Cathode Material



A. Lyashenko

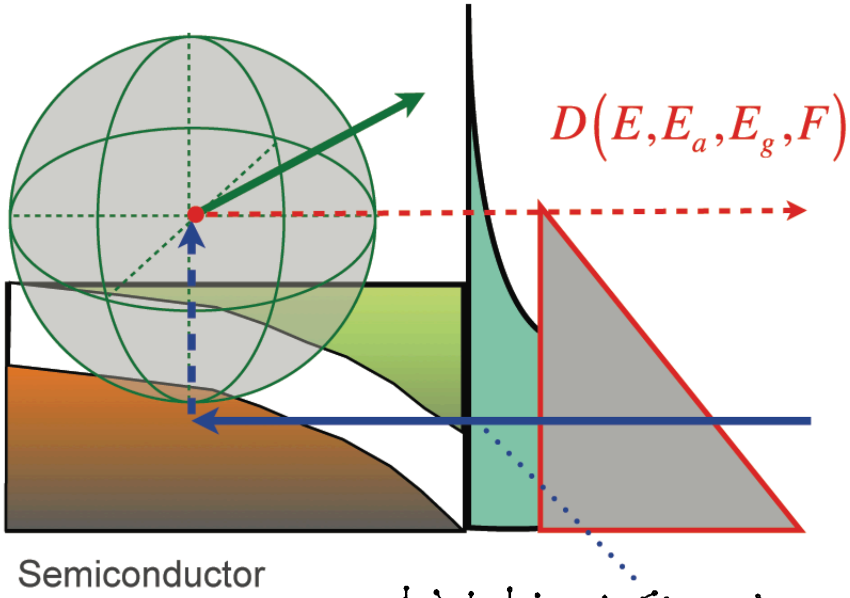
- Multi-alkali are
  - "Obvious" choice in the wavelength range around 400nm
  - Most cost-efficient to produce (Thin-film-technology)
- Selection criteria:
  - Process compatibility
  - Wavelength response
  - Conductivity (large area)
  - High Quantum efficiency
  - Low dark current
  - Robustness (device life time)
- Options:
  - CsK_2Sb
  - KNa_2Sb
  - Cs_3Sb

The Design Concept of the Photocathode Itself



- **QE is defined by many factors:**
  reflection losses, absorption probability, electron transport to surface, and electron emission
- **Cathode is heterogeneous structure:**
  each layer influences the functionality of the others
- **All cathodes discussed are semiconductor cathodes:**
  design principles can be applied to all three classes.

What Determines the Quantum Efficiency



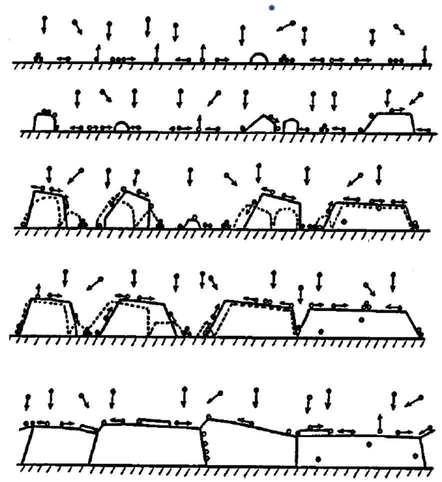
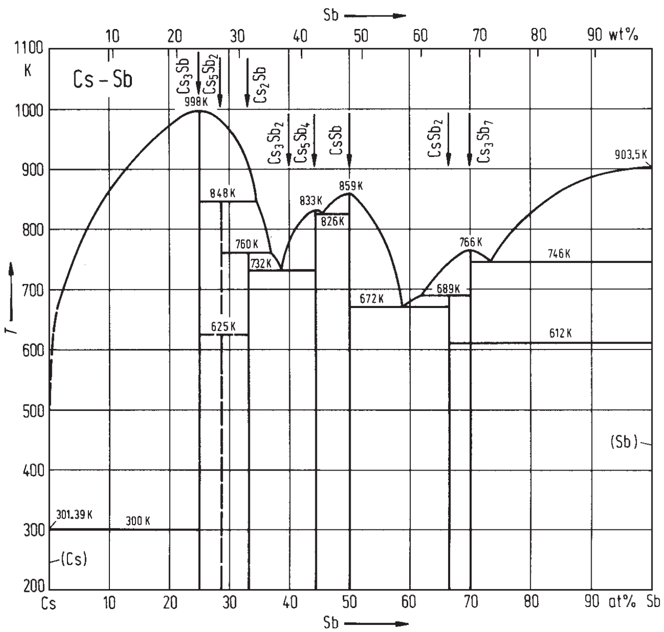
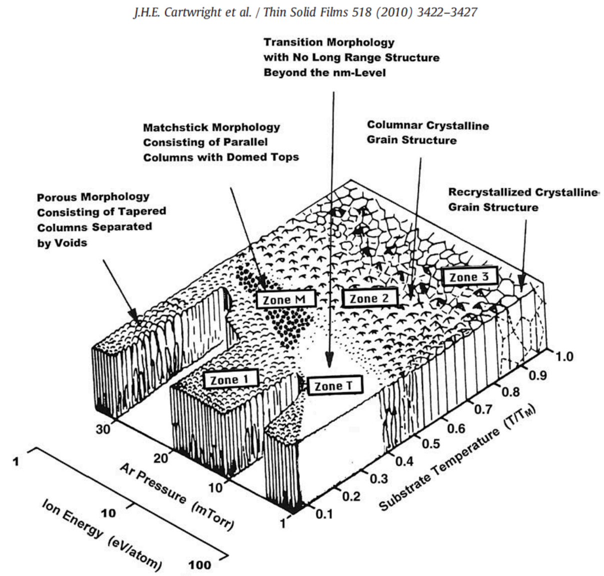


FIG. 1. Schematic diagram illustrating fundamental growth processes controlling microstructural evolution: nucleation, island growth, impingement and coalescence of islands, grain coarsening, formation of polycrystalline islands and channels, development of a continuous structure, and film growth (see Ref. 9).

- Three step model:
  - Absorption
  - Transport to the surface
  - Emission through the surface barrier
  - (reflection losses)
- Ways to manipulate the material:
  - Absorption (band gap & DOS):
    - Band structure by composition variations
  - Transport (scattering):
    - Electron-electron scattering negligible (if not highly doped)
    - Electron-phonon scattering; very difficult to manipulate
    - Electron-impurity scattering; fully growth related
    - Symmetry break (electric fields)
  - Emission properties
    - Surface composition
    - morphology

A Few Thoughts about Thin-Film Growth





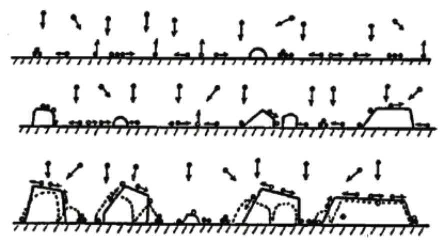
Examples for band-gap variations: K_3Sb

Eg: 1.1eV, 1.3eV, 1.4eV (dependent on crystalline phase)

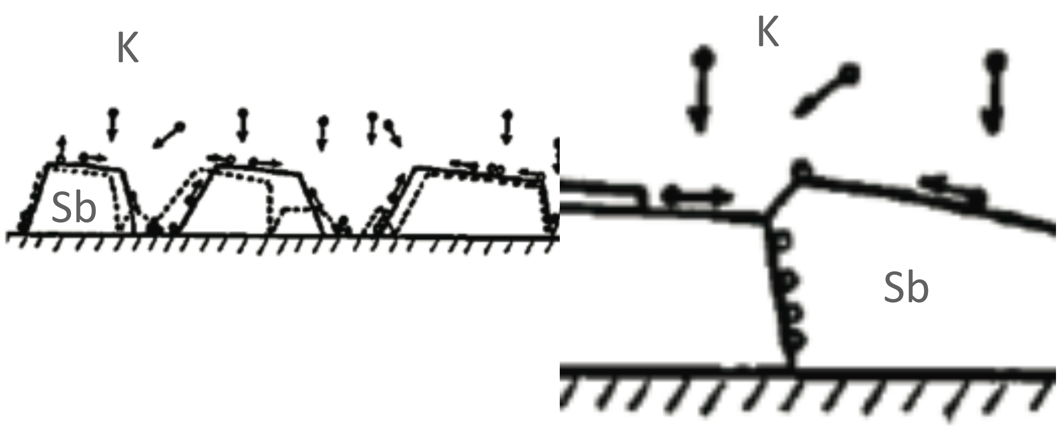
- Film morphology is responsible for
  - Lateral and transversal diffusion rate
  - Impurity scattering
  - Speciation distribution trough out the film
- Recipe parameters and film structure are strongly correlated

How does the Recipe Influence the Growth: The Burl Recipe for CsK_2Sb, an Example

Sb-film growth depends on substrate preparation and layer thickness (wavelength optimization!)



Alkali diffusion depends on structure of Sb-film



1. Surface cleaning (plasma)
2. SbO-growth
3. Sb-metal film growth (thickness is determined by optical reflection
4. K- is inter-diffused (QE measurement as a process parameter)
5. Cs- is interdiffused

Temperature is the driving force
Diffusion &
reaction activation

The Tools (View from ANL)

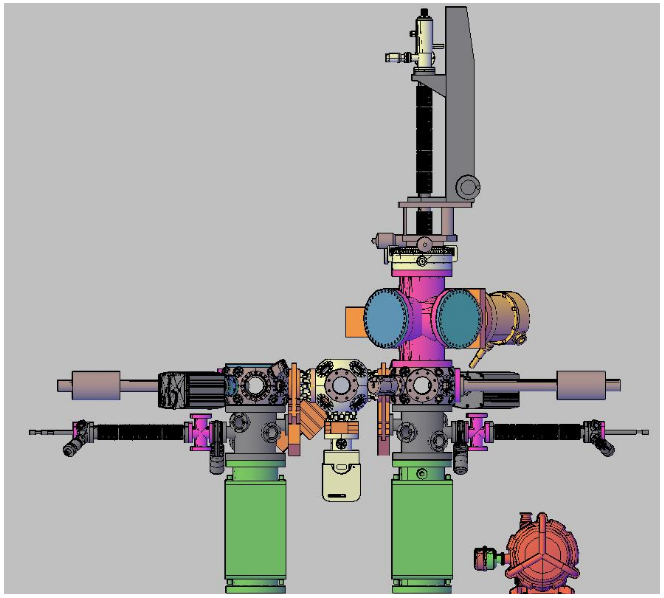
Lab-based tools	• Burle Equipment • Growth & Characterization Chamber • “Calibration” and characterization tools
User-facility based tools	• Visualization of growth: APS (11-ID-D); X21 (NSLS I) • Visualization of activation process: APS (20-ID); X21 (NSLS I)
Industrial approach	• Proto-type Facility (not even started!)
Collaborations	• Know how in growth (SSL, UIUC, WashU,…..) • Data analysis (BNL,University of Copenhagen) • Facilities (mainly x-rays/STM:BNL, Fraser University)

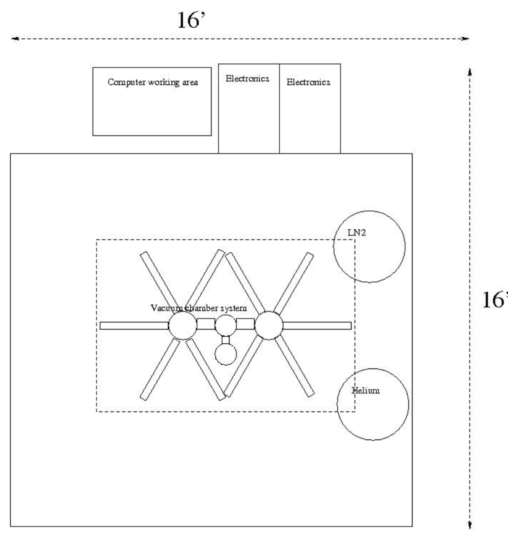
Human Resources / Efforts
Synergy Effects with Other Cathode-Projects

- Project organization: Klaus Attenkofer
- Lab- based tools: Dean Walters (project engineer), Klaus Attenkofer (scientific overview), Zikri Yusof (Burle Equipment), Junqi Xie (postdoc), Anatoli Rohnzin (FNAL/Burle Equipment)
- User-facility based: Klaus Attenkofer (scientific overview), Seon Woo Lee (postdoc);
- Industrial approach: Dean Walters (project engineering), Klaus Attenkofer (scientific input)
- Collaborations:
  - User facilities (x-ray & nano centers): John Smedley + 2 postdocs (BNL), Howard Padmore + 1 postdoc (LBNL)
  - Growth of GaAs: Xiuling Lee + 1 Student (UIUC)
  - Growth and characterization GaN: Jim Buckley + Dan Leopold

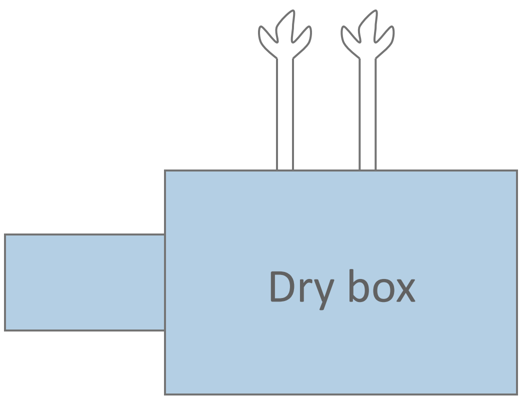
- Efforts: Klaus Attenkofer(25%/25%); Zikri Yusof(25%); Dean Walters (25%), Anatoli Rohnzin (20%), Junqi Xie (100%), Seon Woo Lee (100%)

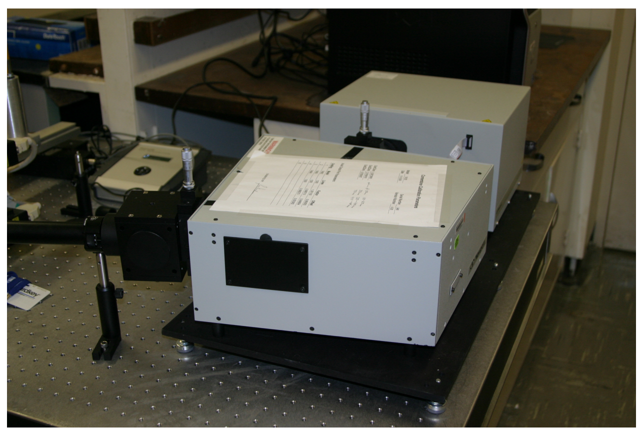
In Situ Functionality Characterization (more info by Junqi)

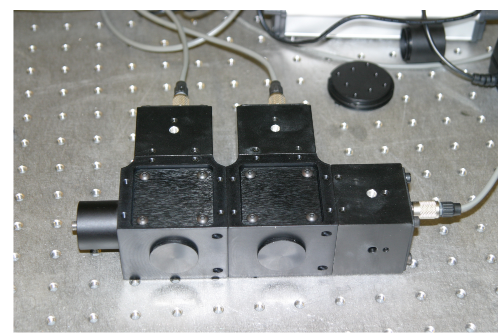




- Growth-chamber:
  - Optical characterization (190nm-1600nm)
    - Reflectivity
    - Transmission
    - Photoconductivity
  - Electrical characterization
    - QE monochromatic
    - QE for process control
    - In plane resistivity measurement
  - Sample preparation instrumentation:
    - In UHV plasma source (SPECS)
    - Thermal evaporators
    - Potentially: sputter gun

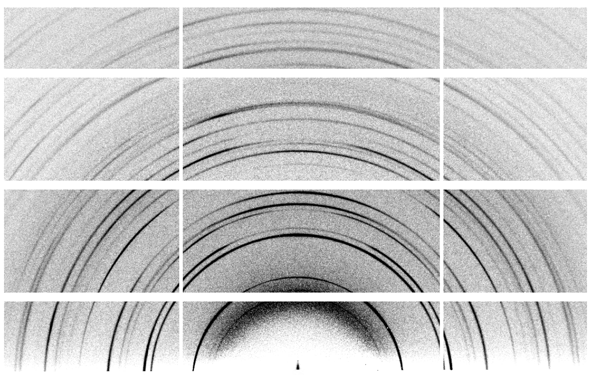


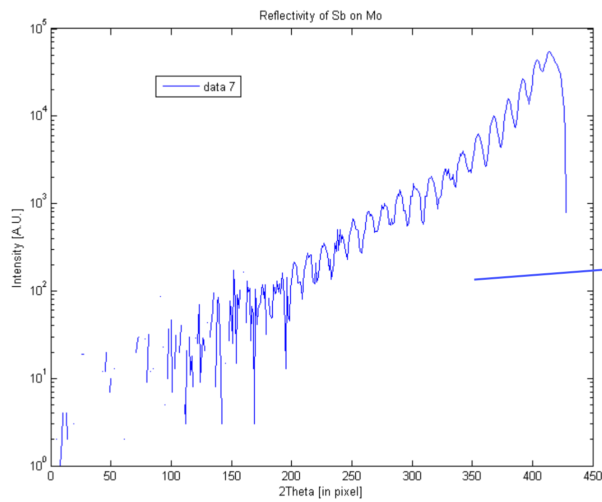


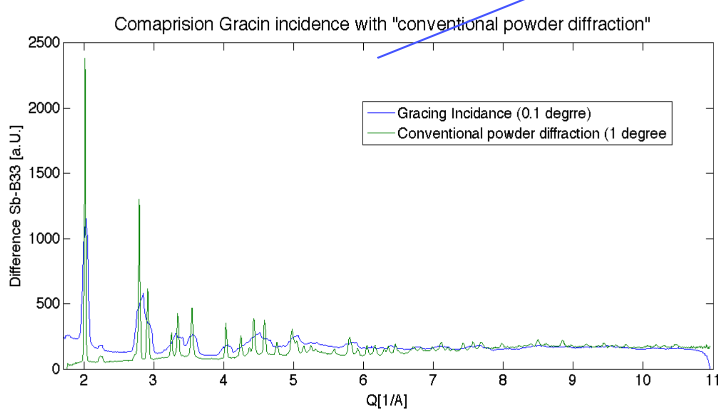


In-Situ Structural and Chemical Characterization

In-situ X-ray Scattering (more by Seon)







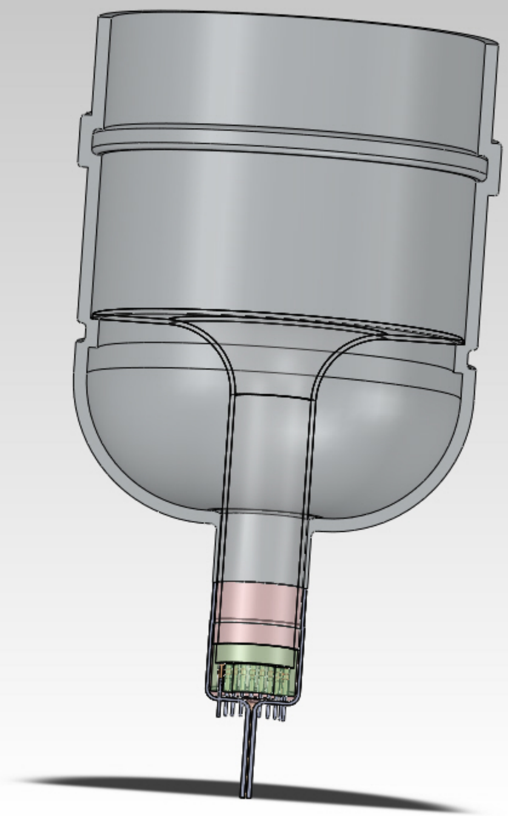
Movie like characterization during the growth:

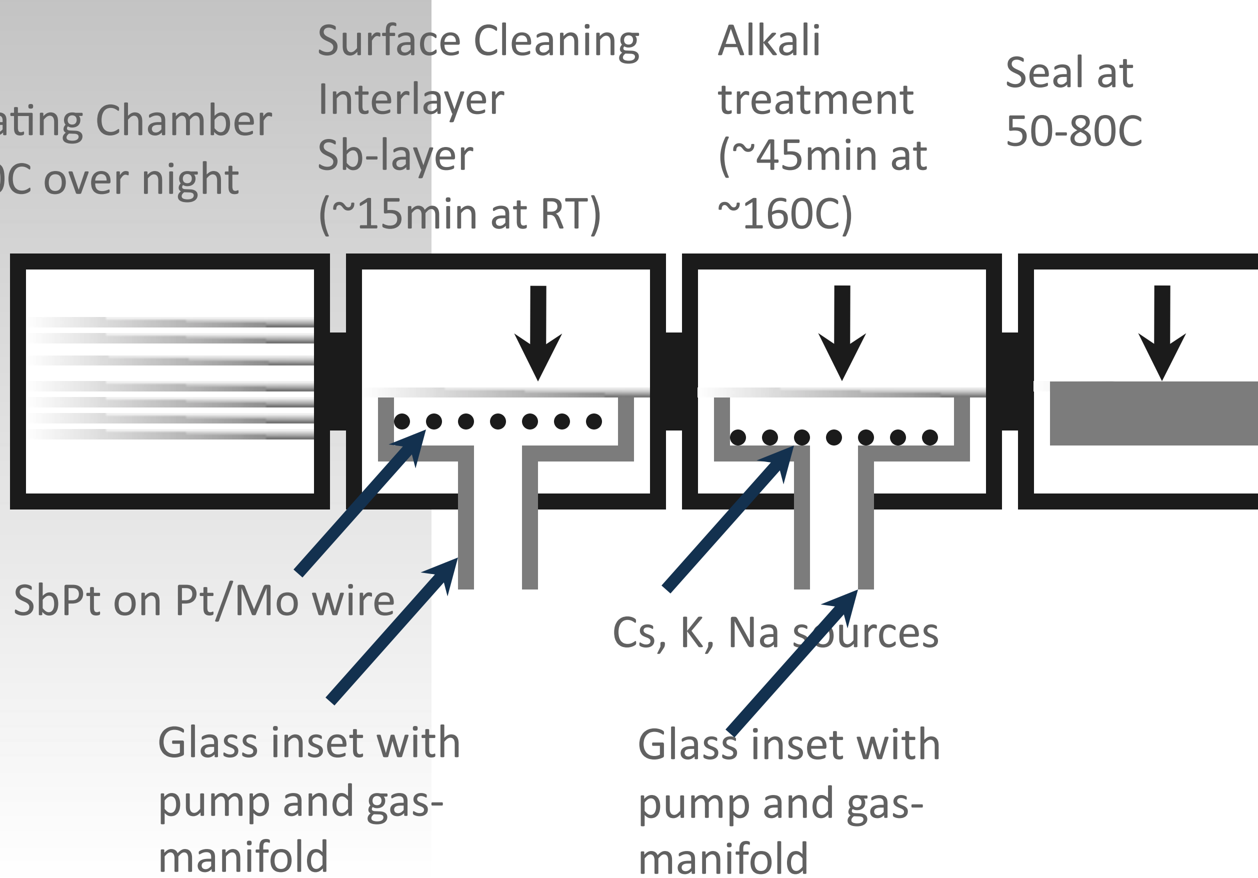
- Macroscopic film properties
  - Film thickness
  - Roughness
- Microscopic composition
  - Which phases are present
  - Lateral and transversal and homogenuity
  - Crystalline size
  - Preferential crystal growth

Surface composition
- Local workfunction
- Chemical composition

PEEM: collaboration with Howard Padmore (ALS)

The "Industrial" Production Unit





One master plate will allow to process cathode and take 1cm diameter test samples

How does “Industrial Production” and Basic Sciences Program Play Together

- Basic growth and cathode physics
- Fundamental correlation between recipe, structure, and functionality
- Scientific output for staff, postdocs and students

- Recipe transport from small to large area
- Source development for large area production

Growth & Characterization Chamber

(Junqi)

Burle Equipment

(Zikri & Anatoly)

User facilities

(Seon)

Industrial Prototype

Facility

(Dean)

- Industrial production compatible recipe development
- Industrial source development
- Prove of concept for new design ideas in industrial environment

The Future

- Demonstrating a clear pathway for knowledge transfer of basic sciences program to production program.
- Developing at least one recipe with high QE (>25%) which can be produced in an industrial way.

- **Long term goals:**
  - Photocathode with 50% QE and wavelength tuning
  - Demonstrating the feasibility of alternative cathodes (III-V)
  - Establishing a photocathode center (collaboration with other labs) which enables
    - Access for general users
    - Cross-correlates most of the main "players"
    - Provides access to state-of-the-art basic sciences tools, fosters collaborations inside the community, and bridges the gap between basic sciences and industry